Operation Procedure for the
Long Trace Profiler:
Windows 95 Version

Steve Irick

18 March, 1998

1. Introduction

1.1 The purpose of this procedure is to give the beginning operator step-by-step instructions for doing the most usual measurement of an optic. Mastering this procedure is considered the necessary minimum for anyone to be certified to operate the Long Trace Profiler (LTP).

1.2 It is assumed that the LTP is completely aligned and needs no adjustment, except for the Surface Under Test (SUT) stage tip and tilt, and for the beam separation adjustment. In fact, it is assumed that the profiler is left in a state from successfully measuring something previously.

1.3 The LTP is much more versatile than indicated in this beginner's procedure. For information on other procedures or theory of operation of the LTP, consult the LTP manual from Continental Optical Corporation. (There will be differences in details of operation, because Continental's production LTP differs in some details.)

1.4 Notation.

1.4.1 It is assumed that the operator is familiar with the most common Windows 95 features.

1.4.2 Things in double quotes " " indicate either Windows menu items or a control in a window.

1.4.3 Step numbers indicate the order in which operations are done. If a section of steps is to be passed over, for example, then go to the next higher section number.

2. Pre-measurement procedure

2.1 Clean shoes; put on appropriate garments.

2.2 Go inside clean area where the Long Trace Profiler (LTP) is, and switch on ceiling lights and HEPA filter f (HEPA filter operation is controversial.)

2.3 Lightly clean dust from the LTP's ceramic beam and the top of the linear DRC glass scale. A small amount of ethanol or isopropanol on a Kimwipe is recommended.

2.4 Turn on air drier unit in main lab room with the switch but not the air valve. The red light on unit should be ON at first, indicating that air is too warm.

2.5 If any package containing optics needs to be opened, this is the time to open it. The package should be opened outside the clean area. Leave dirty packing materials outside the clean area, and bring only the optic with its protective covering inside the LTP room. The optic to be measured is called the surface under test (SUT).

2.6 Turn on computer, monitor, and printer. After the computer has booted, click on "Start", "Programs", "LTPw", "LTPw". The LTPw program starts, and prompts you to choose a project folder where the `Notepad` file resides (Figure 2.1). `Notepad` is the standard Windows 95 text editor, and is used automatically for LTPw text files in the project folders. `Notepad` is expected to be in "C:\Windows\". If the project folder exists for the mirror you will measure, then open the `*.TXT` file in that folder, and append any useful information to the document, including today's date and your initials (Figure 2.2). If the project folder does not yet exist, then click on "Create new folder" (it's an icon) in the File Open dialog box. Give a short, descriptive name to the folder, and likewise for the text file. After saving the file, LTPw is ready to run.

2.7 After the red light on the air drier goes out, open the air to the LTP's air bearing. The valve for this is the yellow handle on the air drier. The open position is when the handle is parallel to the copper pipe. Air will be heard hissing from the LTP air bearing. Go to the front of the LTP and very carefully pull up on the carriage with both hands, until the air bearing is seated to give minimum hissing sound. The carriage should freely move along the ceramic beam.

2.8 Turn on switch to outlet strip above the LTP table. While touching the metal table top with one hand (to discharge any static electricity from you), press the 'output' button on the laser diode power supply. The display should indicate between 40 and 65 ma. Do not adjust this current value. The laser diode power supply should already have been on. At this time the motor amplifier unit should be unplugged.

2.9 Refer to the 'Round Inspection Sheet' and insure that all air pressures, vacuum values, and other items in the lab are acceptable.

2.10 In the LTPw program, click on "Hardware", "Manual Operation".

2.11 Click on "Initialize". If the motor and camera are connected properly, then "Actual Position" will show a number that changes as the carriage moves and the camera output will be displayed as a plot of intensity vs. pixel position. If "Actual Position" does not display properly, click on "Parameters", "Motor Parameters" and make sure that the numbers in edit boxes correspond to hardware jumper positions on the motor controller board that plugs into the PC ISA bus. If neither patterns from the laser diode nor room lights are being displayed, click on "Parameters", "Detector Parameters", and make sure that the address is set properly for the camera board that plugs into the ISA bus.

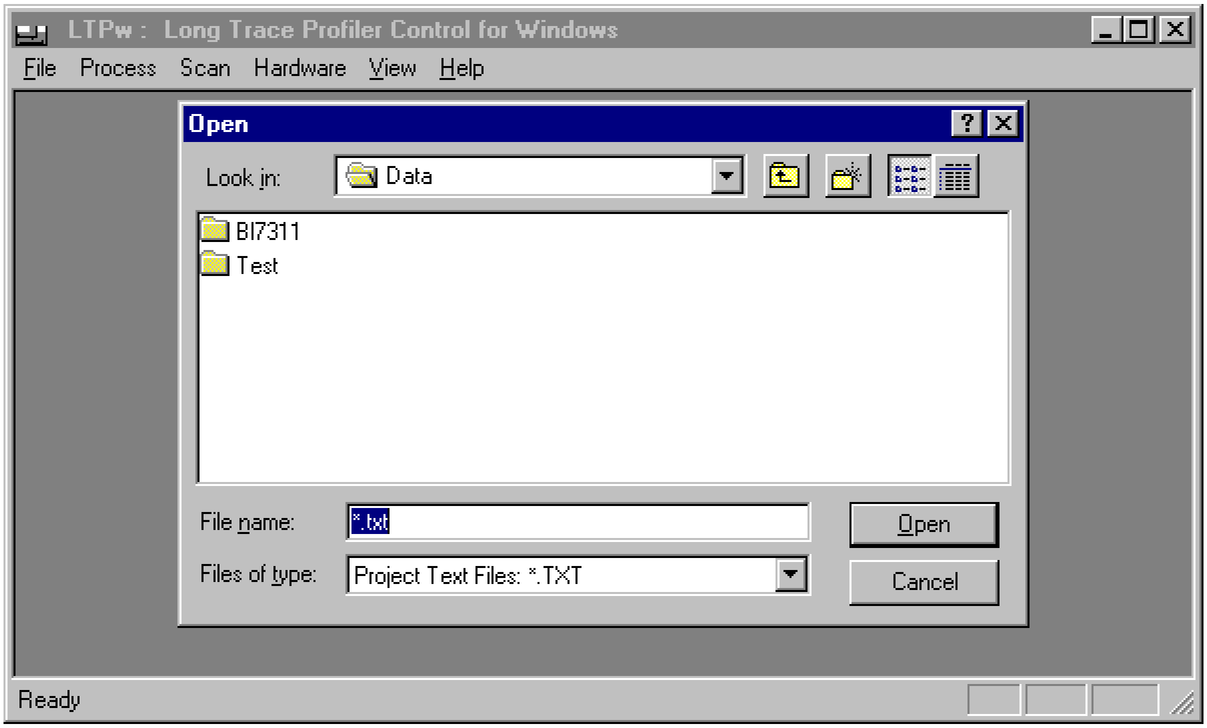

Figure 2.1 Opening the project folder.

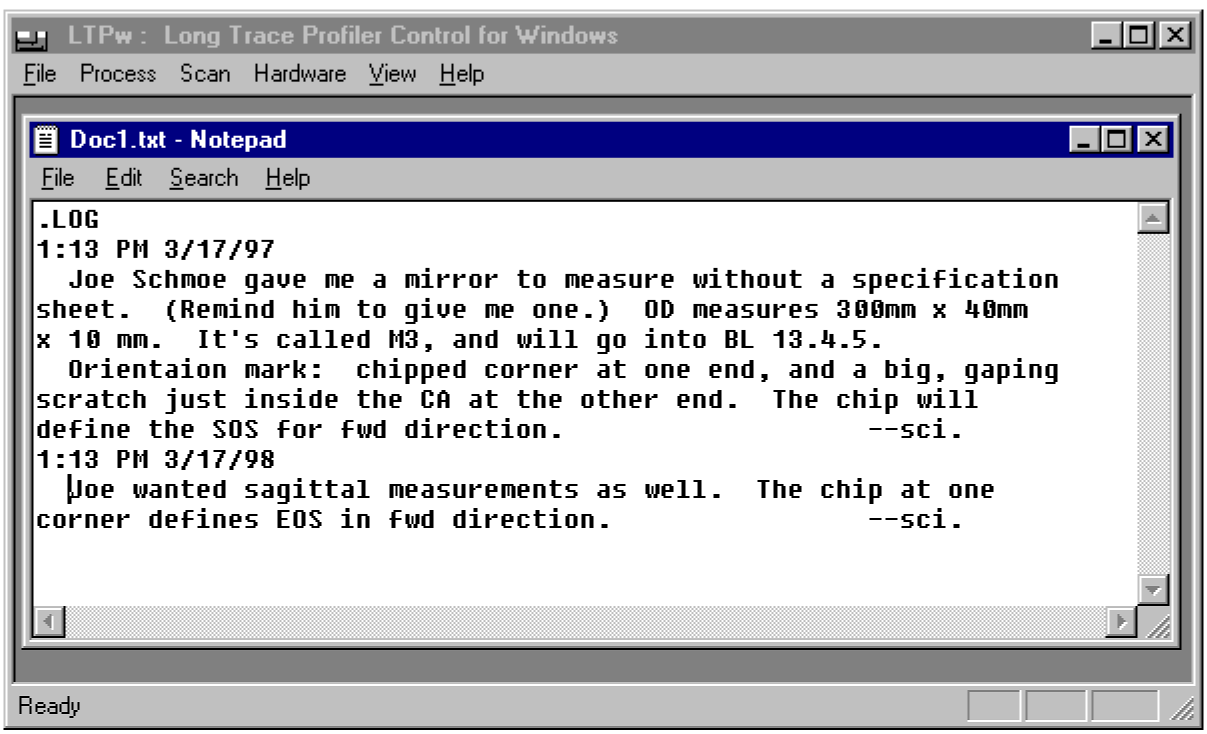

Figure 2.2 Documenting the project.

2.12 Ensure that the limit switches will be hit before any damage can be done to the LTP system when the carriage moves over the length of the stage.

2.13 Lift the brass block which is on the top of the carriage. Move the aluminum stubs out from under the block hangars. Carefully lower the brass block.

2.14 It is now safe to energize the motor. Plug in the motor amplifier unit. The carriage should be difficult to move in the x direction.

2.15 Turn off the HEPA filter fan.

3. Measuring the Surface Under Test (SUT)

3.1 Place SUT on the LTP stage. Adjust the stage orientation with the tip/tilt screws and the large translation stages so that the SUT is in a good measuring position and so that the SUT is nearly horizontal. Make sure that the carriage will not hit anything when it is moved along the entire length of the stage.

3.2 Click on "Motor" so that it is OFF (the "Motor ON" radio button is not dotted); the carriage will now move freely. Set the carriage so that the probe beam is at the left-most edge of the SUT. This position is called the start-of-scan position, or 'SOS'.

3.3 Make sure that the carriage is not drifting, and click on "Initialize". Now the carriage is at x = 0, and the motor is ON, holding that position.

3.4 Determine an appropriate value for "Margin" x_m that will be entered later. Margin is the length needed for the carriage to reach maximum velocity during the constant acceleration period plus a little more for the carriage to reach a stable motion. This "little more" ε is determined experimentally. Thus,

$$x_m = v^2 / (2a) + \varepsilon ,$$

where 'v' is the scan speed (shown in an edit box in the "Measurement Scan" window described later) and 'a' is acceleration (shown in "Hardware", "Parameters", "Motor Parameters").

3.5 Enter a negative number for "Next Position". This number should be round (e.g. x_0 = -50), and the carriage should be able to go to that position without colliding with anything. Also, the absolute value of this number should be greater than "Margin" x_m.

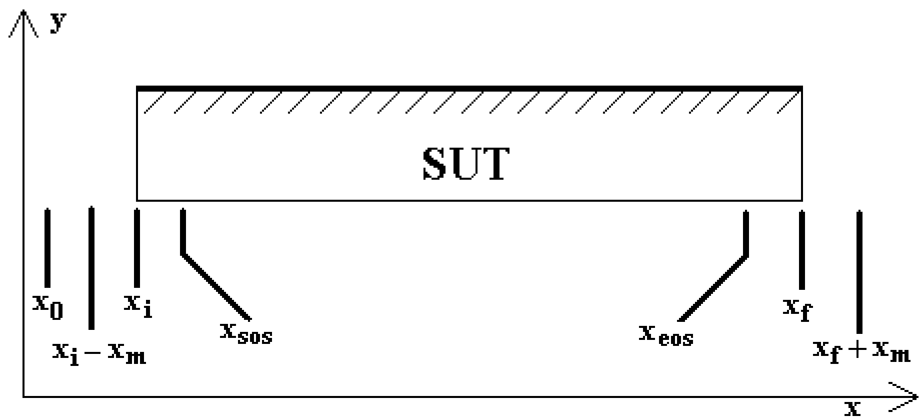

Figure 3.1 Positional relationship of scan parameters.

3.6 Click on "Move". After the carriage has moved to the negative position, click on "Initialize", so that $x_0 = 0$. Using the above example (paragraph 3.5), x_i will now be 50. Refer to Figure 3.1 for a picture of these values.

3.7 Click on "Motor" so that it is OFF. Move the carriage by hand so that the probe beam is at the right-most edge of the SUT. Note the "Actual Position" reading x_f. (The LTP is being used like an expensive ruler.) The center of the mirror will be at $x_c = (x_i + x_f) / 2$.

3.8 Move the carriage by hand to $x_0 = 0$. "Actual Position" and "Desired Position" should both be 0 to within 0.1 mm. Then click on "Motor" to turn the motor ON.

3.9 Enter x_c into "Next Position". Click on "Move". Cover the inside of the internal REF mirror, so that no reference beam light gets into the LTP optical system.

3.10 Adjust the tip and tilt screws of the stage so that the collimated red light from the profiler reflects off the SUT and back into the LTP optical system. Adjust the tip and tilt more carefully, so that this light can be seen on a white card placed just after the LTP lens.

3.11 Using the white card and tip/tilt stage screws, get the light to reflect from the fold mirrors so that there are three reflections from the lower mirror (one from the sloped part of the mirror and two from the level part of the mirror). The pattern from the SUT should now be visible at the detector array, which is indicated by seeing it also on the 'ground glass' screen.

3.12 The intensity pattern should also be visible as a plot in the LTPw "Hardware", "Manual Operation" window. This may be viewed more clearly at a distance by clicking on "View", "Big Picture" and maximizing all LTPw windows. Adjust the tip of the SUT carefully to get the intensity pattern centered in the top detector array, which is plotted as the yellow trace. Avoid getting any of this light in the other array (green trace).

3.13 Perform this step if the reference is used. Remove the cover from the reference beams. Adjust the internal beamsplitter (tip and tilt) so that its pattern is close to the center of the lower detector array, which is plotted as the green trace. Adjust the external reference mirror in the same way. Given that the entire array displays a total slope range of 10 mrad, the two reference patterns should be separated by about 1 mrad.

3.14 Adjust the main intensity control (just after the light source) and the rotating half-wave plate to get the best balance in intensity between all the patterns. This step may have to be done iteratively. A neutral density filter may have to be placed over the half-wave plate to reduce overall intensity of the beams.

3.15 Adjust the beam separation control (knurled knob of the corner reflector's translation stage on the upper right of the optical box) very slightly, so that each intensity pattern consists of a symmetric double peak.

3.16 Determine the ends of the measurement scan x_{sos} and x_{eos}. These will be the points closest to the SUT edges (x_i and x_f respectively) where the SUT intensity pattern is valid, as seen in the LTPw window. If the SUT has significant curvature, these points may be far from the SUT edges. In any case, the intensity patterns must remain on the detector array over the entire measurement scan.

3.17 Move the carriage to $x_0 = 0$.

3.18 Exit the hardware window and click on "Scan", "Measurement Scan".

3.19 Enter the scan parameters into the edit boxes as needed. Again, refer to Figure 3.1 for the meaning of these parameters.

3.20 Click on "Parameters", "Intensity Patterns". Set the pattern sequence to "1,2" if there is one pattern in yellow and two patterns in green; or to "1,0" if there is one pattern in yellow and none in green. Click on "OK".

3.20.1 The other parameters in this menu item may be set to your preference.

3.21 When you are ready to make a measurement scan, click on "Scan".

3.21.1 Enter a filename for holding the intensity data. It is recommended that the same filename be used and written over for all measurements in this project folder, since intensity files can be very large (several megabytes).

3.21.2 Turn off any fans or temperature control equipment. Close the LTP shroud door. Close the LTP room door. Wait about 30 seconds for the air to become calm.

3.21.3 Type in a comment if you wish. Turn off the LTP room lights and click on "OK".

3.21.4 Wait for the SUT to be completely scanned. This is an automatic process.

3.21.5 When the measurement scan is finished, the carriage will automatically return to $x_0 = 0$, if this parameter was set. It is a good idea to set the carriage to zero after each scan. If for some reason LTPw is exited, then "Actual Position" will always be zero when restarting LTPw regardless of the actual carriage position.

3.22 Exit the "Measurement Scan" window.

4. Analyzing the data

4.1 In the LTPw main menu bar, click on "Process", "Intensity to Slope Conversion".

4.1.1 The intensity data file you saved in paragraph 3.21.1 should be listed in the Open dialog box. Double click on this file (`A.INT`). See Figure 4.1.

4.2 The "Intensity to Slope" (I2S) Conversion window appears. The threshold is set to 0.1 by default, but you will probably have to change this level to get I2S to convert all x positions without error.

4.2.1 If you are unsure about where threshold should be, click on "Plotting" so that it is ON, and then click on "Single". (“Rel” compares the threshold to each pattern’s relative height, whereas “Abs” compares the threshold to any pattern as it appears in the plot rectangle.)

4.2.2 If the error message "Nr intensity patterns not expected" pops up , then click on "Ignore" and adjust threshold to a value that will probably work better (Figure 4.2). Make sure that the box "Nr. Patterns" contains the correct sequence of patterns. See Appendix B for more explanation.

4.2.3 Click on "Single".

4.2.4 Repeat steps 4.2.2 and 4.2.3 until all x positions can be converted without error.

4.3 After successful conversion of all x positions, a surface data window should appear for each of the patterns converted (SUT, internal REF, and external REF if three patterns are recorded). Each surface data window displays slope as a function of x, and the I2S window disappears (Figure 4.3).

4.4 If more than one intensity pattern was recorded, then click on "Process", "Multiple Pattern".

4.4.1 The titles of the surface data windows that were generated by I2S should be listed in the edit box labeled "Surfaces". If not, you may change either the window titles or the entry in the edit box.

4.4.2 The box labeled "Respective multipliers" should contain the proper sequence for a linear combination of the slope functions that will yield a corrected slope function. These numbers will depend on the orientation of the detector array with respect to the LTP optical system and angular relationship (magnitude and sign) between SUT, external REF, and internal REF patterns.

4.4.3 Click on "OK". A fourth surface data window will appear that contains the corrected slope function. You must manually close the previous windows if you wish. See Figure 4.4.

4.5 This may be a good time to enter a comment (e.g., temperature during the measurement, orientation of the SUT, and your initials) and to save the surface data file under a unique, descriptive name.

4.6 The 'raw' slope function may have a considerable amount of constant slope component, which is manifest in the height function as tilt. Just as the surface is not affected by a physical tilting of the mirror, so too may the average slope value be subtracted from the slope function.

4.6.1 Click on "Detrend", "Function Fit", "Polynomial". Set "Degree" to "0", and click on "OK".

4.6.2 Click on "Residual function"; click on "OK".

4.7 The surface may have a considerable amount of curvature, which would be represented by a slope function with a straight-line trend. The amount that this line is slanted is proportional to the curvature, which is the reciprocal of the radius of curvature.

4.7.1 Click on "Detrend", "Function Fit", "Polynomial". Set "Degree" to "1", and click on "OK".

4.7.2 Click on "Residual function"; click on "OK". See Figure 4.5.

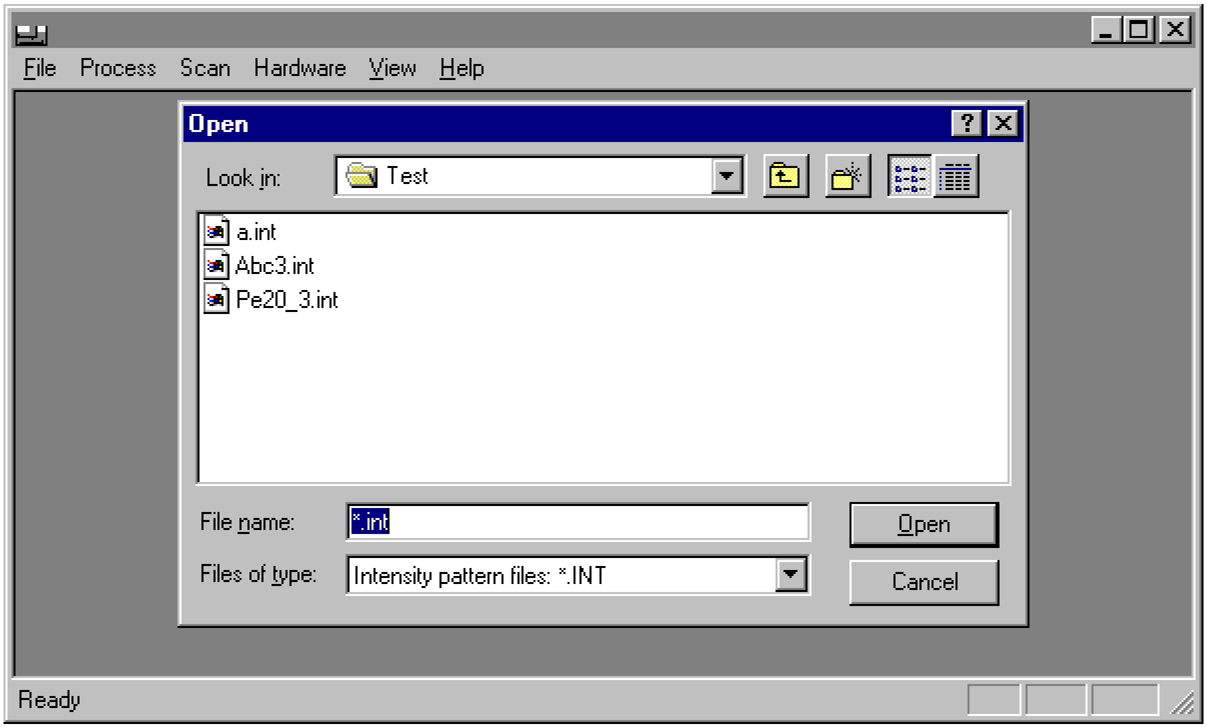

Figure 4.1 Opening the intensity pattern data file.

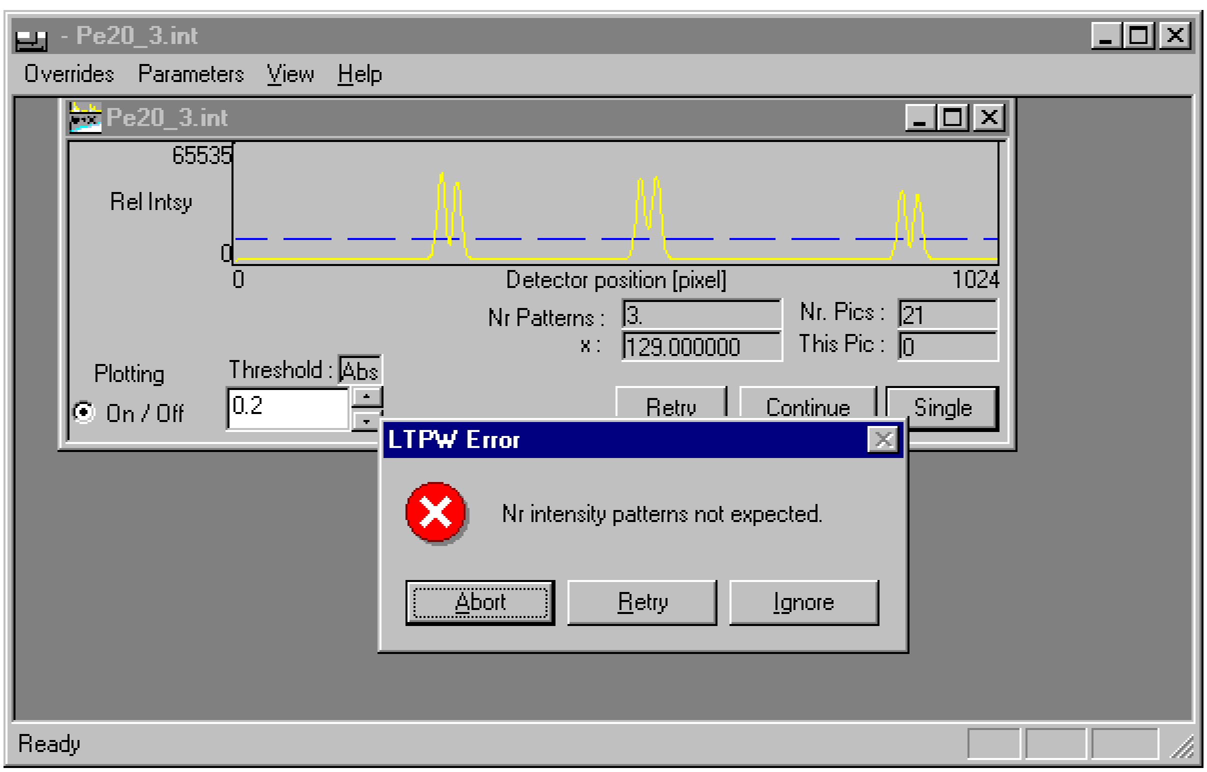

Figure 4.2 Oops; the threshold might be set too high.

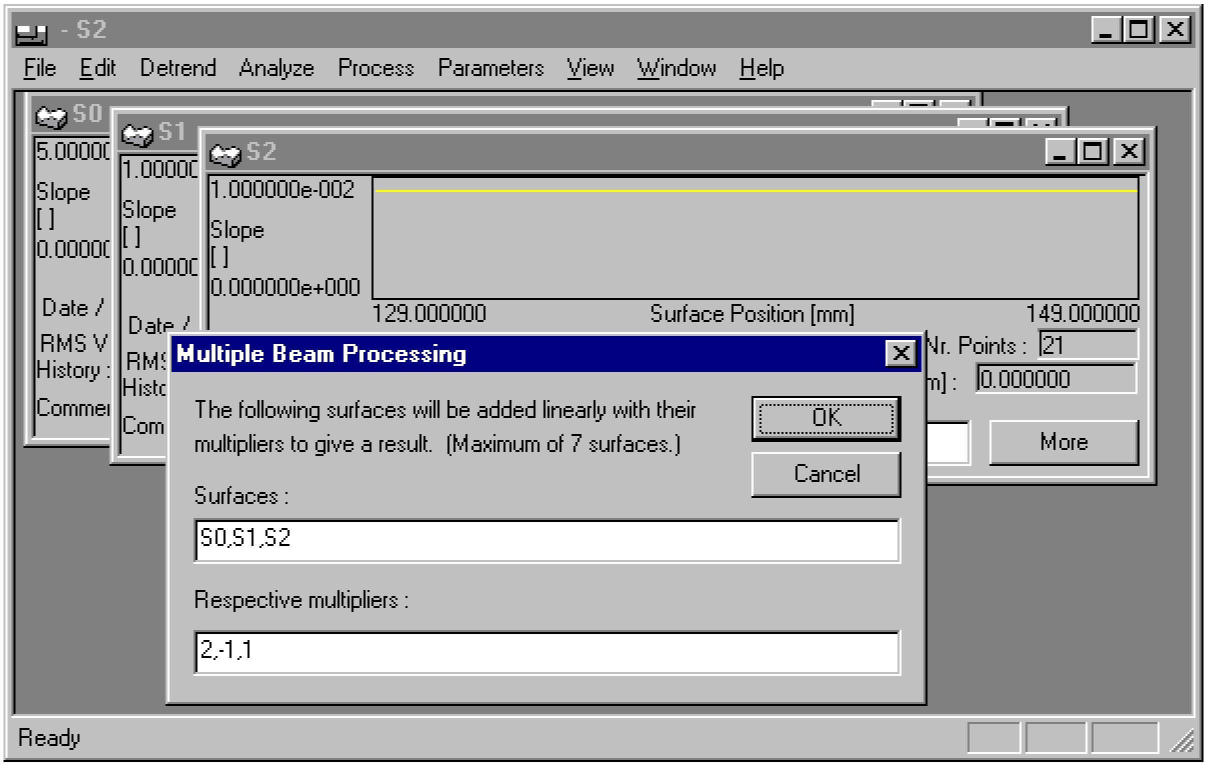

Figure 4.3 Processing the several primitive slope functions ...

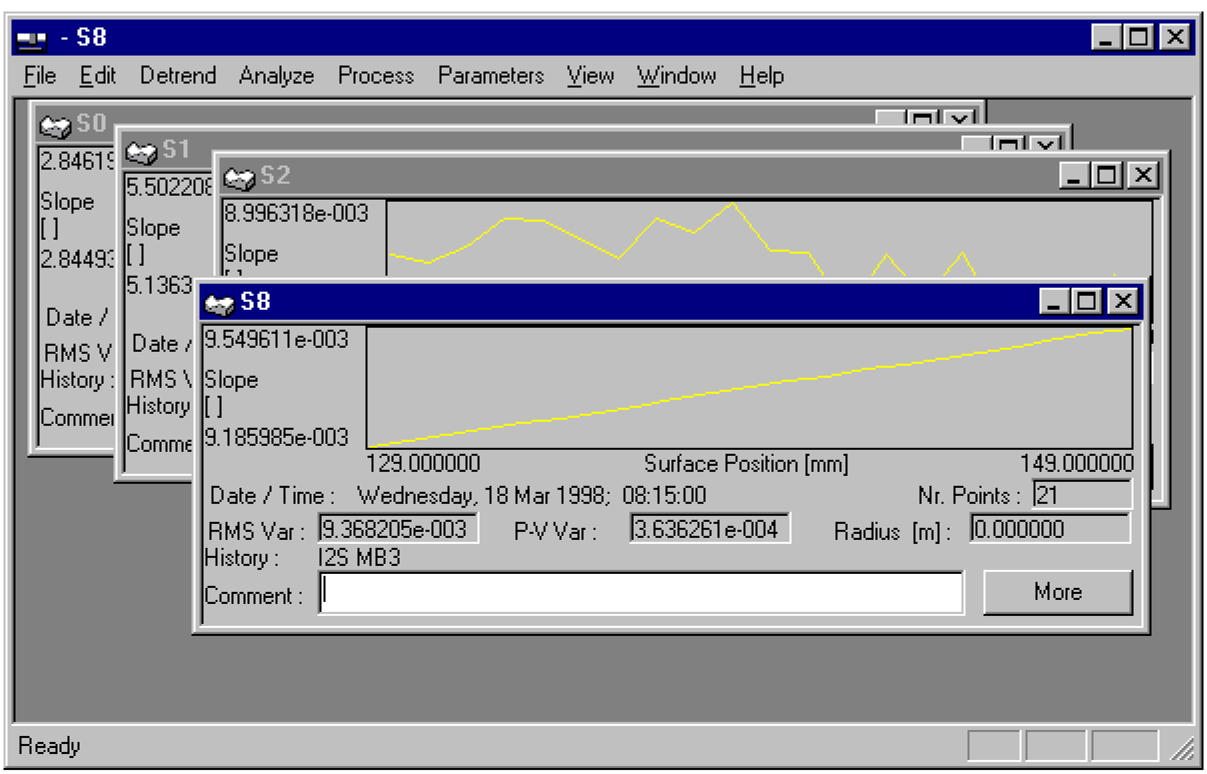

Figure 4.4 ... to give one compensated slope function.

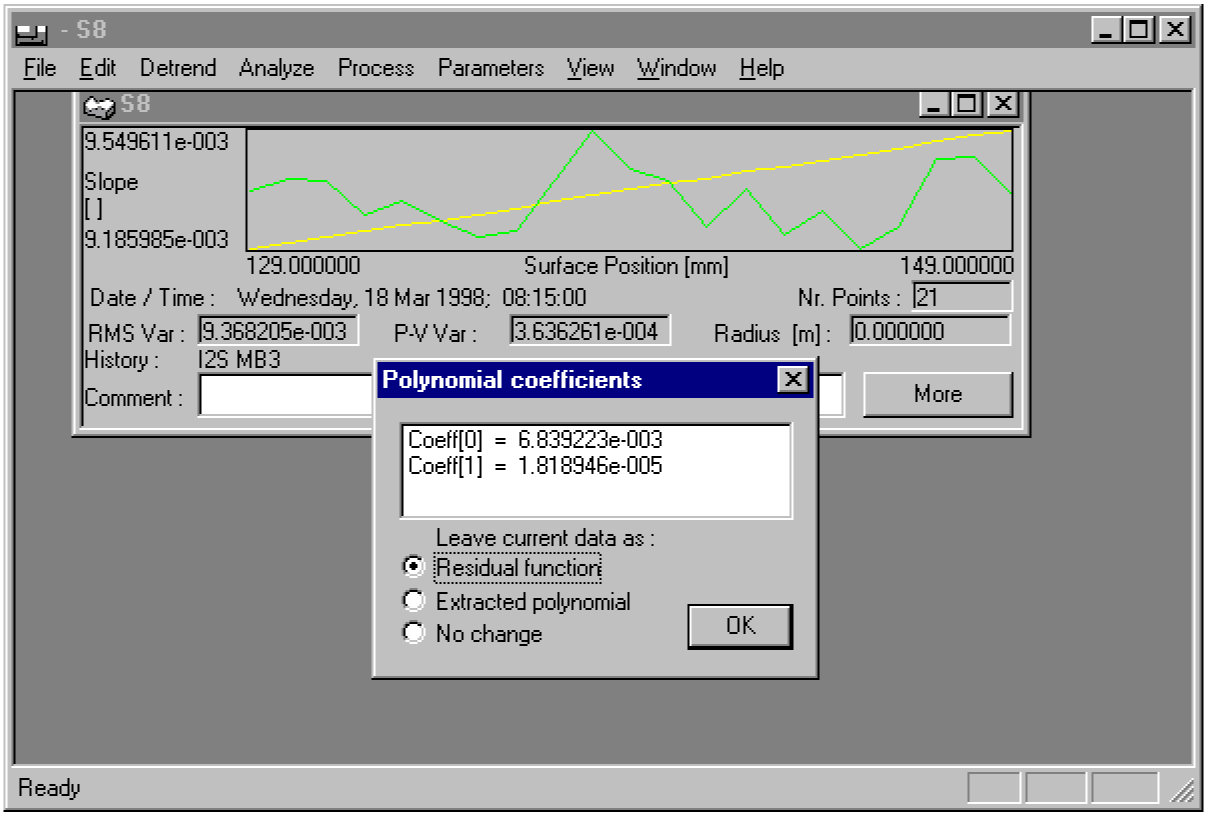

Figure 4.5 Detrending the slope function by removing average curvature.

4.8 If the owner of this optic has specified a clear aperture (CA) to the optic vendor, then the values that are displayed in the current data should be those only for the specified CA. Edit the data to restrict the positions for which the values are valid. As an example, suppose x_{sos} = 100, x_{eos} = 400, and the CA is the center 280 mm portion of the SUT.

4.8.1 Click on "Edit", "Surface Attribute".

4.8.2 Move the mouse cursor to within the edit window plot.

4.8.3 Click in the plot region (with the left button) where you would like the left side of the valid data to begin. While looking at the x position window, keep clicking until you get to the correct x value. Click and drag the green line horizontally over the invalid data region (going just beyond the plot region if you wish), and release the mouse button. Click on "Invalidate".

4.8.4 Click in the plot region where you would like the right side of the valid data to end. Again, keep clicking until you get to the correct x value. Click and drag the green line horizontally over the invalid data region (going just beyond the plot region if you wish), and release the mouse button. Click on "Invalidate".

4.8.5 Click on "OK". The "Edit" window disappears and the invalid regions show in the surface data as a cyan plot. Repeat any detrending above to make them hold for this valid region.

4.9 The surface data in the form of residual slope is likely the most important plot that the beamline designer will get. Save this surface data (edited to include the CA and detrended) with a unique, descriptive filename.

4.10 If the vendor is also interested in the results, he would likely be interested in the residual height profile. Click on "Detrend", "Integrate", "Geometric". In response to "Set current data to this integral?", click on "Yes".

4.11 Many other useful functions are under the "Detrend" menu. For example, to subtract one surface function from another, "Scalar Multiply" one window by "-1" and "Add" it to another surface function.

4.12 The "Analyze" menu provides "Power Spectral Density" and "Histogram" plots of the active surface data window. Examples are shown in Figure 4.6.

5. Shut down

5.1 Unplug power to the motor amplifier unit.

5.2 Lift the brass block that is on the top of the carriage. Move the aluminum stubs over so that the brass block hangars rest on the stubs.

5.3 With one hand touching the metal table top, turn off the laser diode by pressing the 'output' button on the ILX power supply. Do not turn off main power to the ILX power supply.

5.4 Turn off the outlet strip over LTP table.

5.5 Turn off the air valve to the air drier.

5.6 Switch off the air drier compressor.

5.7 Turn off computer, monitor, and printer.

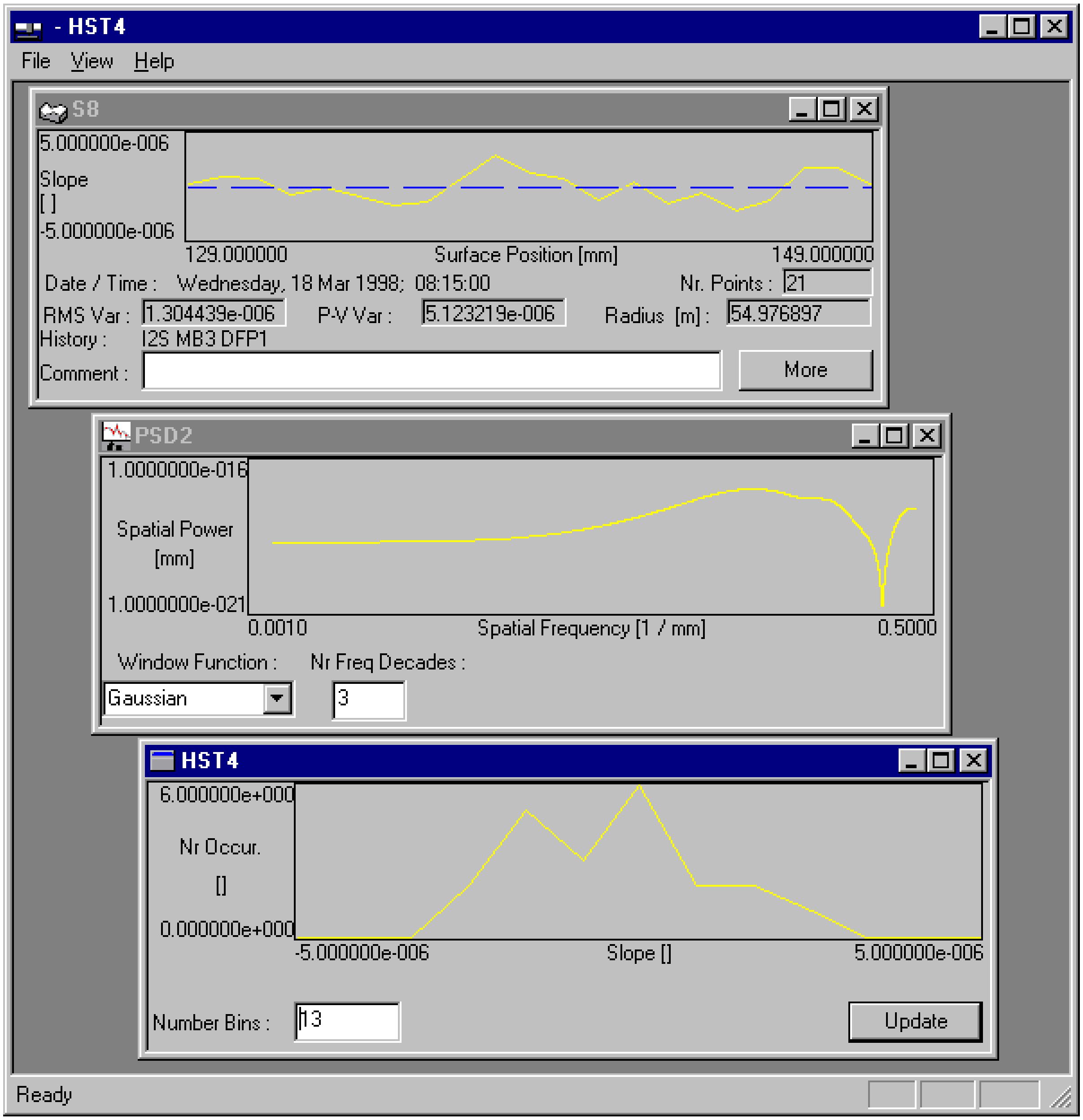

Figure 4.6 Power spectral density and Histogram plots.

5.8 Return SUT to its protective cover, and bring outside the LTP room.

5.9 Turn off fans and lights. Leave the LTP room and close the door.

No equipment should be left running in the LTP room that will dissipate a significant amount of heat, since the HEPA fans will not be running to circulate the air. Heat builds up in the LTP room very quickly. The ILX power supply does not dissipate a significant amount of heat, so leave it on.

6.0 Documentation

6.1 From “File”, “Print ...”, make a printout of the surface. One or two printouts that are representative of the surface should be made; don’t overwhelm the owner with many pages of plots.

6.2 Completely fill out the *Measurement Summary*, signing and dating at the bottom.

6.2.1 Scan length for the LTP section should be for the CA.

6.2.2 The 'Residual Surface Figure' should be the peak-to-valley (P-V) residual height, which is determined by integrating the residual slope as in section 4.10.

6.2.3 'Residual Surface Figure' may contain two entries, if the SUT is nominally flat: one entry for the residual figure if the curvature were not removed (detrending as in section 4.7), and another entry for curvature having been removed (detrending as in section 4.8).

6.2.4 In addition, the mirror vendor may appreciate the residual surface figure given in his terms: the 'number of waves'. Divide 633 nm (one wave of red light) by the P-V variation of the residual height. Enter this result as "λ / result".

6.3 Repack the optic in its outer container, so that it is exactly as it arrived.

6.4 Make copies of the *Measurement Summary*, LTP printouts, and other instrument measurements.

6.5 Return the optic and original of the *Measurement Summary* (with any appropriate LTP printouts and other instrument measurements) to the owner.

6.6 Store copies of the *Measurement Summary*, and all other printouts in the appropriate file folder in the *ALS Optics Documentation* file cabinet.

This ends the LTP procedure.

Appendix A : Slope calibration of the LTP

The LTP is calibrated for accurate slope measurement using the 25mm square diffraction grating in accordance with LSBL-160, "Angle calibration of the Long Trace Profiler using a diffraction grating", 26 Aug 92. The parameter that is set for proper calibration is the Optical System focal length f. This parameter is found in menu items "Hardware; Manual Operation", "Parameters; Optical Parameters".

Procedure: Remove internal beamsplitter and any mirror on the table. Replace the external reference mirror with the grating so that orders are separated vertically. Get the two strongest orders to appear on one array and nothing (not even ghosts) on the other array. In "Scan; Measurement", set "Intensity Patterns" to "2,0" and make a measurement scan over the length of the profiler travel with an interval of maybe every 10mm. After converting I2S, subtract one slope function from the other (using "Detrend; Scalar Multiply" by -1.0, and then "Detrend; Add" the other surface title). The difference slope function will have an RMS variation v of about 3.8 mrad. To solve for the corrected focal length f, calculate:

$$f = v * fo / 3.8804,$$

where fo (found in "Parameters; Optical Parameters") is the previous value for f. Replace fo with f.

Update the text document in the "Calib" folder with entries like these:

25 Apr 97 calibration: was 1200.0; now 1202.8 [mm]. --sci.
28 Apr 97 cal: was 1202.8; now 1206.558; --sci.

Appendix B : Setting the Intensity Pattern Sequence

In the older DOS version the operator performed a measurement scan with three beams if he was using any reference beam at all. (The words 'beam' and 'pattern' are used synonymously here. A 'beam' is a bundle of light rays from the laser source that goes through the LTP optical system. Each beam produces an intensity 'pattern' on the detector array.) The pattern from a particular beam is seen within each picture that the camera takes. Thus for each x position there would be three patterns in the intensity data file. (See LSBL-290 "LTP Measurement Scan Conventions" [1] for definitions of these terms.) An I2S conversion was done on each pattern set to give a slope function for each pattern. Then an external program TBP.EXE processed the three resulting slope functions to give a fourth slope function, which was the corrected slope function of the mirror. TBP.EXE simply performed a linear combination of the three slope functions in accordance with "Improved measurement accuracy in a long trace profiler: Compensation for laser pointing instability", Nuclear Instruments and Methods in Physics Research, Vol. A347, (1994), 226-230 [2].

In LTPw (Windows 95 version), more flexibility is given the operator so that any number of patterns can be used, and the patterns can be in any sequence. The operator should still use the reasoning in [2] so that the measurement is compensated properly. From [2], Equation (4)

$$s(x) = [M(x) + R(x) - 2L(x)] / (-2),$$

if three patterns are used. If two patterns are used (e.g. if pointing error L (x) is combined with R (x) using a Dove prism), then

$$s(x) = [M(x) + R(x)] / (-2).$$

This nomenclature assumed that one detector array was used. R (x), M (x), L (x) were the right, middle, left patterns on the array, respectively.

In LTPw, if three patterns are used with a single array detector, then "Nr. Patterns" would be "3". After I2S processing, three slope functions will appear, and the next step is to click on "Process", "Multiple Pattern". A dialog box appears that allows the operator to change the sequence of patterns in the linear combination. If the three patterns are arranged on the one array from left to right as L, M, R, then "Surfaces" will be "S0,S1,S2", and "Respective Multipliers" should be "2,−1,−1". If the camera has been rotated 180°, then all the slope measurements are reversed, and "Respective Multipliers" would then be "−2,1,1".

In LTPw, if two patterns are used with a single array detector, then "Nr. Patterns" would be "2", "Surfaces" will be "S0,S1", and "Respective Multipliers" should be "−1,−1".

In LTPw, if three patterns are used with a dual array detector such that the SUT pattern is on the first trace (yellow), the internal REF is at left on the second trace (green), and the external REF is at right on the second trace (green), then "Nr. Patterns" would be "1,2", "Surfaces" will be "S0,S1,S2", and "Respective Multipliers" should be "−1,2,−1".

In LTPw, if two patterns are used with a dual array detector such that the SUT pattern is on the first (yellow) trace and the only REF pattern is on the second (green) trace, then "Nr. Patterns" would be "1,1", "Surfaces" will be "S0,S1", and "Respective Multipliers" should be "−1,−1".

However, if a dove prism is used in the REF beam, then "Respective Multipliers" should be "-1,1". Again, "Nr. Patterns" will be "1,1" and "Surfaces" will be "S0,S1". This is the arrangement used by the ALS/OML most often in 1998.

If a slope calibration is to be performed using a grating in accordance with Appendix A, then (using a dual array detector) there will be two patterns on the first trace (yellow), and none on the second trace (green). In this case, "Nr. Patterns" would be "2,0", "Surfaces" will be "S0,S1", and "Respective Multipliers" should be "−1,−1" or "1,1".